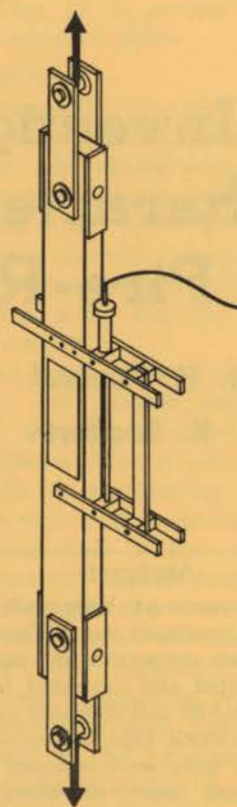

TECHNICAL NOTE NO. 6

Small Homes Council–Building Research Council, University of Illinois at Urbana-Champaign

INVESTIGATION OF THE MECHANICAL CHARACTERISTICS OF TRUSS PLATES ON FIRE-RETARDANT-TREATED WOOD

Donald H. Percival, Research Associate Professor of Wood Technology and Utilization, SHC–BRC
Stanley K. Suddarth, Professor of Wood Engineering, Wood Research Laboratory, Purdue University

Twenty-five Cents

FPRS FOREST PRODUCTS JOURNAL VOL. 21, NO. 1 JANUARY 1971

An Investigation of the Mechanical Characteristics of Truss Plates On Fire-Retardant Treated Wood

D. H. Percival

S. K. Suddarth

Abstract

Systematic comparison has been made of the influence of a fire-retardant treatment on stiffness and ultimate strength of metal plate connectors and nail-glued plywood plates. Matched, treated and untreated tensile specimens were made of Douglas-fir and southern yellow pine using long-tooth and short-tooth type connectors and plywood nail-glued plates. All tests were repeated at each of two wood moisture content levels. An overview of the test results indicates that slightly lower ultimate strengths can be expected when fire-retardant treated lumber is used. Joints made with fire-retardant treated lumber are somewhat stiffer than the controls at 20 percent moisture content but this difference is lost as the lumber dries.

THIS INTRODUCTORY STUDY was designed to compare the load-slip and strength characteristics of several truss plate connectors in fire-retardant treated wood (FRT). No documentation could be found in the literature on the behavior of truss plates with this material and, if experimental data have been assembled by any organization, they are not commonly available. The National Design Specification[1], a standard guide for designing wood and timber structures, requires a reduction of 10 percent in the design properties of FRT wood if re-dried after treatment and 20 percent reduction if not re-dried. Fabricating any component or truss with lumber at 20 percent moisture content or higher is not recommended although it is commercially available in this condition.

Increased availability of FRT wood has opened new markets for wood-frame construction in areas where so-called non-combustible materials have held unique positions. Additionally, the apparent growing concern over the fire safety of light frame buildings, restaurants, nursing homes, schools, and the like, has caused some code authorities to require that the framing, trusses, and other structural components be fabricated with FRT lumber. Some trusses presently are being built with FRT lumber, often without adequate engineering data. These forces for increased use of FRT lumber undoubtedly will generate an increasing demand for basic information.

The pilot study reported here was designed to answer some questions about the properties of joints made with truss plates and fire-retardant treated lumber and how they would react to tensile forces. It was also intended for those with an interest in the subject to assess future informational needs. The study obviously is not designed to supply all the information we need on this important subject. The study was initiated as the result of a voluntary meeting of a committee of persons concerned with the various aspects of the use of FRT framing lumber. Various organizations were represented at this session: the Forest Products Division, Koppers Company, Inc., the U.S. Forest Products Laboratory, the Truss Plate Institute, Purdue Wood Research Laboratory, and the Small Homes Council of the University of Illinois. This study was designed, using selected truss-connector plates, to test tension specimens for load-slip and load to failure characteristics. It is hoped that a subsequent phase will include long-term load tests on full-scale trusses, and some actual fire tests on roof sections.

Procedure

Design of Study

Three truss-plate types were examined by tensile-joint tests using FRT lumber along with matched specimens of untreated lumber. The tests were duplicated on two species, Douglas-fir and southern yellow pine, for each plate type and also duplicated at two moisture content levels, 20 percent and 10 percent. The objective

[1]National design specification for stress-grade lumber and its fastenings. 1968 edition. National Forest Products Association, Washington, D.C.

The authors are, respectively, Research Associate Professor of Wood Technology and Utilization, Small Homes Council, University of Illinois at Urbana-Champaign, Ill., and Professor of Wood Engineering, Wood Research Laboratory, Purdue University, Lafayette, Ind. The authors wish to acknowledge the cooperation of the Koppers Company in providing treatment and adhesives, the Truss Plate Institute in providing metal plates and fabrication, and C. S. Walters of the Department of Forestry, University of Illinois, for assisting in the design of the study. This paper was presented at Session 7 — Wood Engineering — of the 24th Annual Meeting of the Forest Products Research Society, June 30, 1970, in Miami Beach, Fla. It was received for publication in June 1970.

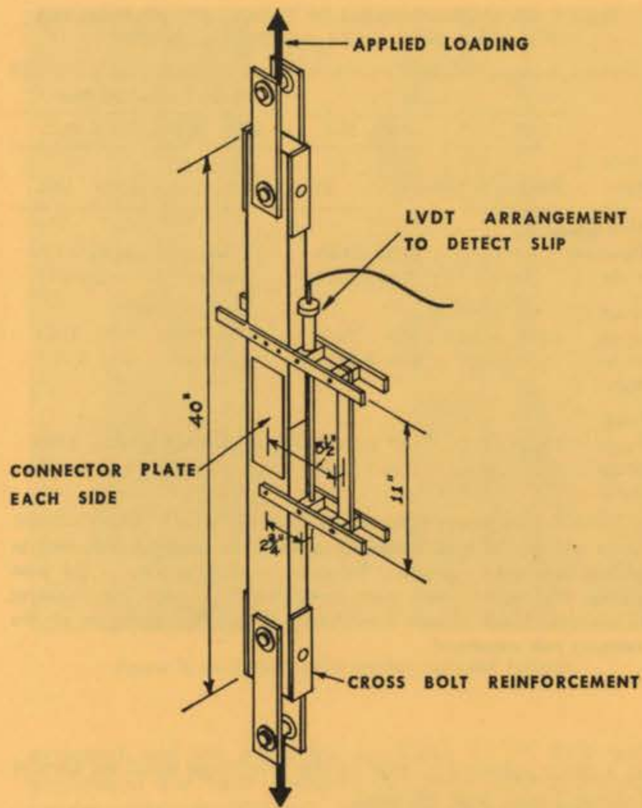

Figure 1. — Tensile test specimen showing direction of applied load. In addition to measurement of ultimate strength in resisting the applied load, the specimen was also instrumented to detect slip.

was not to compare one plate with another but to compare the treated material characteristics with untreated material characteristics of each of the widely varying plate types. A typical test specimen is pictured in Figure 1.

One hundred specimens were included in the study, according to the breakdown shown in Table 1. Five specimens are included in each category, which represents a species, wood treatment, plate type, and moisture content. Because the bonding of FRT wood is difficult using commonly available adhesives, an adhesive designed specifically for FRT lumber and requiring a moisture content range of 9 to 12 percent moisture content was used. Thus, no 20 percent content specimens were included for plywood plates.

Table 1. — BREAKDOWN OF NUMBERS OF SPECIMENS UNDER EACH CATEGORY OF LUMBER TREATMENT, SPECIES AND MOISTURE CONTENT.

Plate Type	Douglas-Fir				Southern Yellow Pine			
	20% M.C.		10% M.C.		20% M.C.		10% M.C.	
	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.
Nail-Glued Plywood Plate*	—	—	5	5	—	—	5	5
Short Tooth Metal Plate	5	5	5	5	5	5	5	5
Long Tooth Metal Plate	5	5	5	5	5	5	5	5

*Glued plywood plates — adhesive requirements: 10% average wood moisture content.

Specimen Preparation

The specimens were cut from 8-foot 2 by 4's ($1\frac{1}{2}$ by $3\frac{1}{2}$ inches) obtained from commercial suppliers. The lumber was selected from stress-rated stock, "1500f" or better, as commonly used for truss construction. Four 20-inch pieces were cut from each 8-foot 2 by 4. Pieces were alternately assigned to treated and untreated specimens to provide end-matching. The pieces were then placed in a dry kiln and conditioned to 20 percent moisture content.

The pieces to be treated were weighed to monitor moisture content, and pressure-treated with Koppers' "Non-Com" (R) interior fire-retardant solution, at a commercial installation. After treatment, the pieces were returned to the kiln for conditioning. Sample slices taken from extra pieces were used to determine moisture content for the treated stock by the ovendrying method. Resistance-type moisture meters could not be used in the FRT wood. This indirect process provided estimates of the moisture content of the test specimen pieces. When specimens were transported, such as to the fabricator, they were wrapped in polyethylene film to maintain their specific moisture content. Several checks were made throughout the program with an electric moisture meter on the reliability of this protective procedure with the untreated specimens. No change in moisture content was noted in any of these measurements and it was, therefore, presumed that the procedure was satisfactory for both specimen types—treated and untreated.

A "short-toothed metal plate" and a "long-toothed metal plate" were selected for the study in consultation with the Truss Plate Institute. The third type was a nail-glued plywood plate which is uniquely different from the usual mechanical connection.

Tests

Each specimen was stressed in tension in a universal testing machine and loaded as shown in Figure 1. The platen speed was 0.035 inches per minute. The specimen was loaded to failure in a single process. A chart record of load versus total slip of the joint was plotted during the earlier part of the loading. The plot included the linear or design range of the fastener plus a part of the plastic-flow range.

A linear variable differential transformer (LVDT) extensometer, (Fig. 1) was used to obtain joint deformation data. This extensometer was used in place of a pair of dial gages because it enabled us to plot a continuous record of load-deformation data with less labor and risk of human error. Loads were transmitted to the specimens through 1-inch pins inserted in holes in the ends of the wood members. We also used a 3/8-inch cross bolt with large washer plates to reinforce the wood around the hole since load levels sometimes exceeded 7000 pounds.

Results

Examination of the load-deformation curves showed them to be generally typical of wood connection

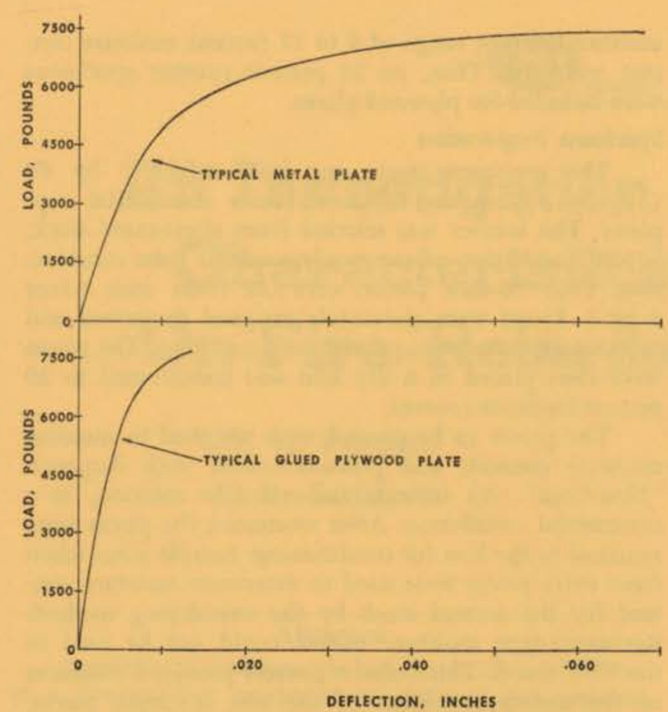

Figure 2. — Typical load-deformation records showing the characteristic behavior of a typical mechanical connection above and a typical glued plywood plate in the lower graph.

behavior (Fig. 2). A linear or nearly linear behavior was apparent at the beginning load levels, which gradually developed into marked curvilinearity as the increment of slip per increment of load increased more rapidly. In the case of the metal plate connectors, the late slip stage increase proceeded to a prolonged deformation with minor load increase until failure was reached. The plywood plates, on the other hand, behaved in a more brittle fashion, with the load climbing

Table 2. — AVERAGE VALUES OF CONNECTION STIFFNESS FOR FIVE SPECIMENS IN EACH INDICATED CATEGORY. [1]

	Douglas-Fir				Southern Yellow Pine			
	20% M.C.		10% M.C.		20% M.C.		10% M.C.	
Plate Type	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.
Nail-Glued Plywood Plate	No Tests		6645	7680	No Tests		5685	6120
			$t = 1.33$				$t = 0.581$	
Short Tooth Metal Plate	4620	3585	2550	2850	4365	3660	3675	3765
	$t = 3.337$		$t = 1.523$		$t = 5.182$		$t = 0.583$	
Long Tooth Metal Plate	6885	4470	2467.5	2272.5	6060	4980	2775	2745
	$t = 5.374$		$t = 1.166$		$t = 2.518$		$t = 0.189$	

[1]Joint stiffness is here arbitrarily defined as the load increment in pounds required to produce 0.010 inches deformation in the joint during the initial, low load level portion of the test. Student t statistics * are shown immediately below the averages of the category pair concerned.

$*t_{.05} = 2.306$

at a more substantial rate in the late stage until an abrupt failure point was reached.

The load-deformation chart records were used to determine a stiffness figure for each connection tested. A straightedge was placed on the lower, approximately linear portion of the load-deformation curve at a slope considered to be average for this lower portion. The straight line thus established was used to determine the load increment required to produce an arbitrarily chosen 0.01 inch slip. This load increment then becomes the basis for comparison of stiffness between categories tested. The five individual values in each category were

Table 3. — ULTIMATE LOAD VALUES IN POUNDS FOR INDIVIDUAL TEST SPECIMENS IN EACH OF THE CATEGORIES INDICATED.[1]

Plate Type	DOUGLAS-FIR				SOUTHERN YELLOW PINE			
	20% M.C.		10% M.C.		20% M.C.		10% M.C.	
	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.
			5325 △	7400 □			5650 □	6600 □
Nail-Glued			6225 □	6900 □			5075 □	6275 □
Plywood Plate	No Tests		4300 □	7650 □	No Tests		5280 □	6515 □
			6150 □	6875 □			5275 □	7015 □
			5425 □	7425 □			5660 □	5995 □
	6550 ○	7900 ✕	4050 ○	5575 ○	6925 ✕	7240 ◆	7475 ✕	6800 ✕
Short Tooth	6450 ○	6475 ○	6525 ○	7550 ✕	6400 ○	7680 ✕	6925 ○	7950 ✕
Metal Plate	7450 ✕	7825 ✕	5950 ○	7125 ✕	7275 ✕	7350 ✕	7350 ○	8000 ✕
	7300 ✕	7275 ✕	7050 ✕	7800 ✕	7125 ✕	7625 ✕	7375 ✕	7375 ✕
	7175 ✕	8125 ✕	6000 ○	7875 ✕	7550 ✕	7025 ✕	7375 ✕	7475 ✕
	6875 ○	7350 ○	6075 ○	7950 ○	8575 ✕	8875 ○	8250 ○	8600 ○
Long Tooth	7475 ○	8325 ○	7200 ○	8050 ○	8325 ○	8700 ○	8150 ○	8325 ○
Metal Plate	8175 ○	8375 ○	6200 ○	7375 ○	7675 ○	7875 ○	8175 ○	7775 ○
	8125 ○	7900 ○	6025 ○	7875 ○	8250 ○	9200 ○	8575 ○	9250 ✕
	7000 △	8650 ✕	7000 ○	8150 ○	6575 ○	7425 ○	8675 ✕	9575 ○

[1]The symbols to the right of the strength figures denote the observed mode of failure: ○ Plate elements pulled out of wood, ✕ Plate failure in metal, □ Rolling shear failure in plywood, △ Member failure in connection zone, ◆ Member failure outside connection zone.

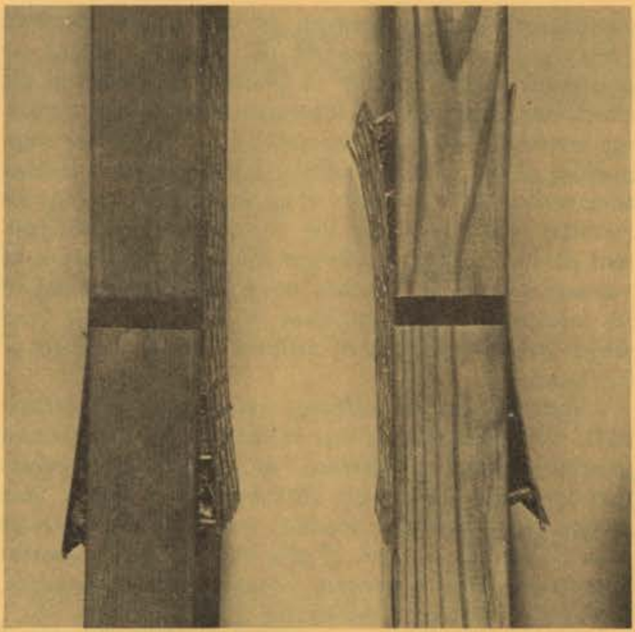

Figure 3. — Typical plate element pull-out failures.

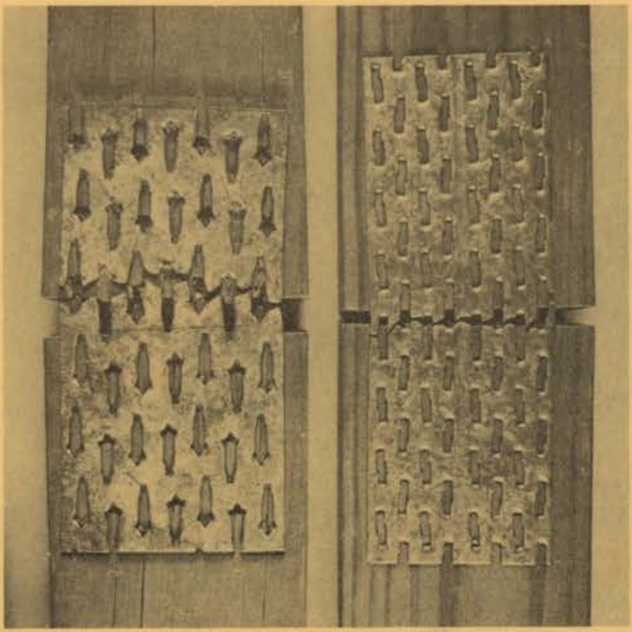

Figure 4. — Typical plate failure in metal.

averaged and are presented in Table 2. "*t*" tests were performed for each possible category comparison and results appear in Table 2, immediately below the averages to which they pertain.

The ultimate strength test results (Table 3) display characteristics that are somewhat difficult from the analytic standpoint in that five modes of failure were observed. Each of these failure modes justifies some detailed discussion which follows.

Plate Element Pull Out — This is a common type of failure with mechanical plate connections where the nails or teeth are withdrawn from the wood as the lateral loads on them are increased. The pulling of fasteners along the extremities of the plates is often called peeling and initiates due to moments that exist in planes perpendicular to the plate. In later stages of connection failure, wood is crushed by lateral forces of the nails or teeth which, in concert with the peeling action, contributes to final failure of the connection. Figure 3 is a photograph of this type of failure in short and long tooth type metal plate connections.

Plate Failure in Metal — This type of failure occurs when the net section of steel in the plates is inadequate relative to the number and strength of the nails or teeth. The occurrence of this mode of failure in the test specimens is an indication that the plates used were too large in nail numbers to produce the desired consistent pull-out that was expected when the experiment was planned. Figure 4 shows this type of failure in short-toothed and long-toothed metal plate connections.

Rolling Shear Failure in Plywood — This is a common type of failure encountered in glued plywood connections in which failure occurs in plies with grain directions perpendicular to the principal load direction. Figure 5 shows a typical failure of this type.

Member Failure in Connection Zone — This occurred only twice. In one case a brash type wood failure occurred between the plates (Fig. 6). The other case occurred in a plywood specimen between the plates due, apparently, to extreme cross grain in the member. This latter failure is also pictured in Figure 6.

Member Failure Outside Connection Zone — This occurred only once and appeared in the nature of a horizontal shear failure originating in the region of one of the load pin holes at the end of a member (Fig. 7). This failure precluded further loading of the specimen but a substantial load of 7,240 pounds was sustained at the time.

The ultimate strength data are given in Table 3 as individual values including a symbol that designates the mode of failure. Horizontally adjacent pairs of values in the treated and untreated columns are from matched specimens cut from the same 2 by 4. Averages in the categories do not appear because in many cases their use could be misleading, due to the presence of mixed modes of failure. The object of presentation in this table is, then, to provide an original view of the data.

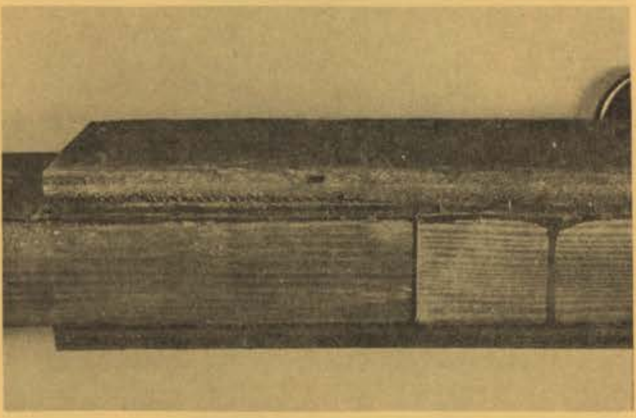

Figure 5. — Example of typical rolling shear failure in plywood.

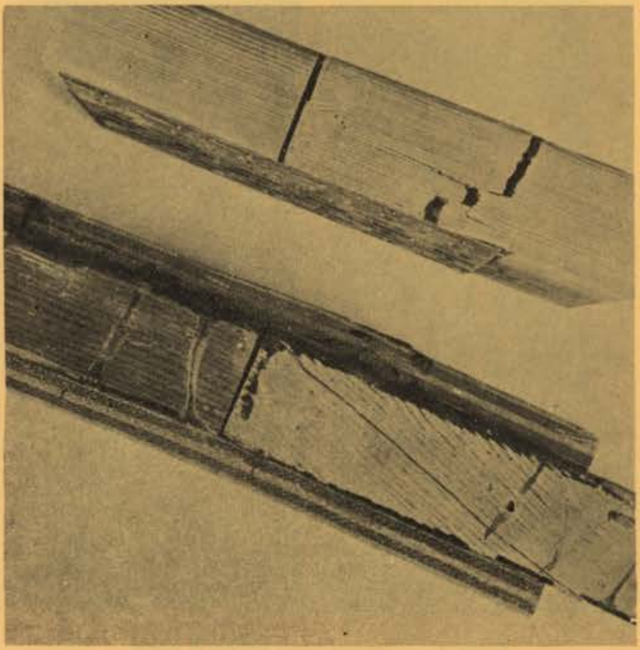

Figure 6. — Brash-type wood failure above and cross-grain failure below.

Conclusions

Stiffness

The stiffness data are summarized in Table 2 which shows averages in each five specimen category along with t test results that compare the treated average with the untreated average for each pertinent category pair. In all cases the 10 percent M.C. specimens showed no significant difference between the treated and untreated averages. Since service ranges of moisture content are reasonably represented by 10 percent, this leads to the conclusion that load-slip information from tests involving untreated wood can be applied in dry service engineering design with treated wood. This notion is further substantiated by the results of an analysis of variance for factorial design utilizing the 10 percent moisture content data only. The results are shown in an analysis of variance (Table 4). Neither wood treatment nor any of its interactions are significant at the 5 percent level which indicates its lack of influence on the stiffness of the joint.

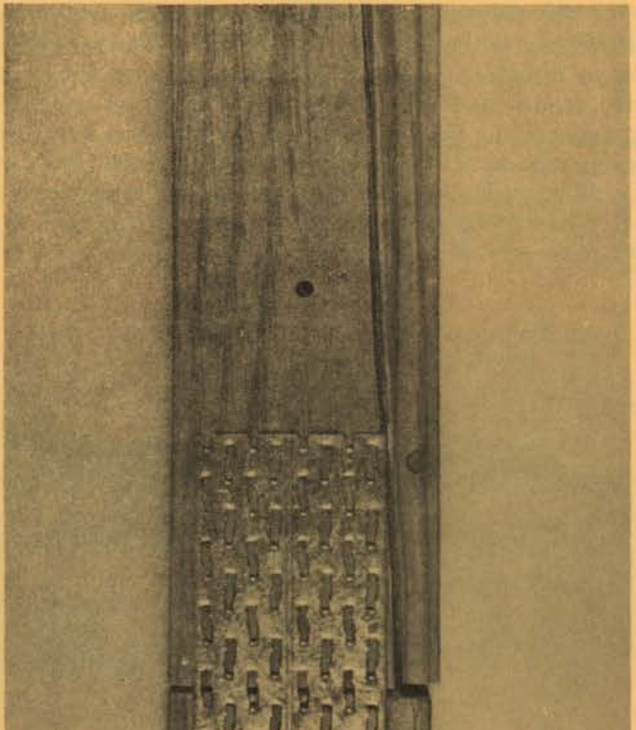

Figure 7. — Horizontal shear failure in lumber.

Examination of stiffness averages at 20 percent M.C. in Table 2 shows that treatment has a significant increasing effect on stiffness in all cases. This means that structures built with FRT lumber at higher than service range moisture contents will have stiffer joints than if untreated wood of the same moisture content were used. This temporary advantage will disappear, however, as drying to the service level progresses.

In summary, the main conclusion here is that special considerations for load-slip effects in FRT lumber are not necessary in present day wood engineering practice for dry service conditions.

Strength

The presence of three predominant modes of failure along with two occasional other types suggests some change in specimen design for further experimentation. This is particularly true for the metal plates in which case the plates should be shorter in longitudinal dimension relative to their effective cross section to assure tooth pullout when this is the mode of failure of principal interest. Conversely, the plates should be lengthened to raise the chances of metal failure when this is of primary interest. The scattering of mode of failure present in Table 3 could be eliminated in this way.

Table 5 shows category averages of values taken from Table 3 having the same mode of failure within the category pair as indicated by the symbols in the table. Student t tests of the difference between averages in the pairs are also given.

The rolling shear strength of the plywood plates was adversely affected by the FRT treatment as indicated by the significant t values obtained in both Douglas-fir and southern yellow pine test groups.

Three sets of untreated and treated data pairs provided sufficient data for an analysis of the ultimate strength of the short tooth plates used. These plates

Table 4. — ANALYSIS OF VARIANCE.

Source of Variation	F Ratio	$F_{.95}$
Connector Plate Type	169.72	3.19
Wood Species	0.07	4.04
Wood Treatment	2.08	4.04
Plates x Species	12.98	3.19
Plates x Treatment	1.72	3.19
Species x Treatment	0.32	4.04
Species x Plates x Treatment	0.34	3.19

Table 5. — AVERAGES OF ULTIMATE STRENGTH OF CONNECTIONS AND UNPAIRED VALUES OF STUDENT'S t.[1]

Plate Type	DOUGLAS-FIR				SOUTHERN YELLOW PINE			
	20% M.C.		10% M.C.		20% M.C.		10% M.C.	
	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.	Treat.	Unt.
Nail-Glued Plywood Plate	No Tests		5525.0 □	7250.0 □	No Tests		5388.0 □	6480.0 □
			$t = 3.65$				$t = 7.07$	
Short Tooth Metal Plate	7308.3 ×	7781.2 ×	Insufficient Data		7218.8 ×	7420.0 ×	7408.3 ×	7520.0 ×
	$t = 2.40$				$t = 1.01$		$t = 0.50$	
Long Tooth Metal Plate	7662.5 ○	7987.5 ○	6500.0 ○	7880.0 ○	7706.2 ○	8415.0 ○	8287.5 ○	8568.8 ○
	$t = 0.84$		$t = 4.88$		$t = 1.37$		$t = 0.72$	

□ Rolling shear failure in plywood

× Failure of metal plate

○ Failure by pulling teeth from wood

[1]In each cell of the table only those values of the single mode of failure, shown by symbols, were used in the analysis. Paired value student t statistics, not shown, were also calculated where possible but did not lead to different results from those shown.

turned out to be proportioned so that the metal failure was more frequent than pullout of the teeth. Little difference is expected here since these results pertain to plate strength, which is not normally presumed to be directly dependent on the type of treatment or the moisture condition of the wood. Although the three t values for short toothed plates in Table 5 do not indicate a difference due to wood treatment, the relations among the three average pairs show that the untreated specimens consistently displayed higher average plate strength. Grouping all three sets of data so that 10 specimens of plate failure on treated wood could be compared with 13 specimens of plate failure on untreated wood produced average strengths of 7302 pounds and 7570 pounds, respectively. A t test ($t = 2.13$, 21 degrees freedom) indicated these averages to be significantly different at the 95 percent level of confidence. This outcome suggests the possibility of effects of the treatment chemicals on the areas of stress concentration where microscopic or submicroscopic cracks in the metal can be expected from the punching process of manufacture. The evidence is not strong enough here to draw firm conclusions regarding the interaction of plate strength and treatment but it does suggest further consideration and possible study. The importance of this point becomes apparent when it is realized that the specimens were tested only 3 to 4 months after fabrication. Although questions are raised as to whether the apparent difference in strength is present on a longer term basis and to what extent, these questions cannot be answered from the results of this study.

The long tooth plates happened to be proportioned so that tooth pull-out was the predominant failure mode. An examination of the t tests of average pairs of Table 5 shows that the Douglas-fir 10 percent M.C. specimens were the only category pair to show a significant difference. The lack of significance in the other cases should be digested carefully, however, since the averages are, again, always higher for the untreated specimens. If the untreated specimen averages are taken as a basis, the following percentages of average strength loss for the FRT specimens are calculated.

Douglas-fir, 20 percent M.C. - - - - - - -	4.1 percent loss
Douglas-fir, 10 percent M. C. - - - - - - -	17.5 percent loss
Southern yellow pine, 20 percent M.C. -	8.4 percent loss
Southern yellow pine, 10 percent M.C. -	3.3 percent loss

These figures generally support the 10 percent reduction for FRT lumber required by the National Design Specification. This conclusion, being necessarily drawn from a relatively small set of data, amplifies the need for further experimentation with larger samples.

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